Breast Cancer Among Radiologic Technologists

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Objective. --To evaluate the risk of breast cancer among women occupationally exposed to ionizing radiation.

Design. — Case-control study.

Participants. --A health survey of 105 385 women radiologic technologists certified by the American Registry of Radiologic Technologists since 1926. Among 79 016 respondents, 600 breast cancer cases were identified. Each of 528 eligible subjects with breast cancer was matched to five control subjects based on age, year of certification, and follow-up time.

Main Outcome Measures. --Relative risk (RR) estimated as the relative odds ratio for breast cancer over categories of years worked as a radioiogic technologist and according to personal and occupational exposure characteristics.

Results. --Study subjects had been certified for a mean of 29 years; 63.8% of cases and 62.6% of controls worked as radiologic technologists for 10 years or more. Significant increased risks for breast cancer were associated with early age at menarche (for<11 years of age: RR=1.79; 95% confidence interval [Cl], 1.09 to 2.94), nulliparity (RR=1.36; 95% CI, 1.04 to 1.78), first-degree relative with history of breast cancer (RR=2.07; 95% CI, 1.56 to 2.74), prior breast biopsy (RR=1.53; 95% Cl, 1.17 to 2.00), alcohol consumption (for >14 alcoholic drinks per week RR=2.12; 95% Cl, 1.06 to 4.27), thyroid cancer (RR=5.36; 95% Cl, 1.64 to 17.5), hyperthyroidism (RR= 1.66; 95% Cl, 1.02 to 2.71), and residence in the northeastern United States (RR=1.66;95% CI, 1.19 to 2.30).Jobs involving radiotherapy, radioisotopes,orfluoroscopic equipment, however, were not linked to breast cancer risk nor were personal exposures to fluoroscopy or multifilm procedures. Use of birth control pills, postmenopausal estrogens, or permanent hair dyes also were not risk factors. Based on dosimetry records for 35% of study subjects, cumulative exposures appeared low. Among women who worked more than 20 years, the RR for breast cancer was 1.13 (95% Cl, 0.79 to 1 .64).

Conclusions. --More than 50% of the reported breast cancers could be explained by established risk factors. Employment as a radiologic technologist, however, was not found to increase the risk of breast cancer. The contribution of prolonged exposure to relatively low dosesof ionizing radiation to breast cancer risk was too small to be detectable at this time.

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A STUDY OF radiologic technologists occupationallyexposed to radiation during several decades has public health relevance, since the most common exposures experienced by the general population are from periodic low-dose radiation in the course of medical care, environmental circumstances, or occupational situations. Most radiologic technologists are female and thus at risk for cancer of the breast, an organ known to be susceptible to induction by radiation, even from fractionated exposures.[1] In this article, we examine the riskof breast cancer associated with occupational and medical exposures to radiation while controlling for the influence of all recognized risk factors.

METHODS

Population

The original study population consisted of 148 517 radiologic technologists who had been certified by the American Registry of Radiologic Technologists(ARRT) for at least 2 years during 1926 to 1982.[2] A questionnaire was mailed to 132 519 registrants known to be alive (99 272 women and 33 247 men); 99 272 responses were received. Nonresponders were contacted by telephone, resulting in an additional 14 324 responses (9506 women and 4818 men) to an abbreviated questionnaire (total response rate=79%). The descriptive features of the questionnaire survey have been reported previously.[2] Several sections of the questionnaire were similar to parts of the Nurses' Health Study, which assessed risk factors for cancer and heart disease among women older than 30 years.[3]

Table 1.—Characteristics of Radiologic Technologists With Breast Cancer (Case Subjects and Matched Controls)

Characteristic	No. (%) of Case Subjects*	No. (%) of Controls*
Total	528 (100)	2628 (100)
Birth year		
<1930	242 (45.8)	1126 (42.8)
1930-1939	154 (29.2)	862 (32.8)
1940-1949	108 (20.5)	521 (19.8)
1950-1960	24 (4.6)	119 (4.5)
Year certified		
1926-1939	23 (4.4)	113 (4.3)
1940-1949	104 (19.7)	519 (19.7)
1950-1959	204 (38.6)	1016 (38.7)
1960-1969	146 (27.7)	725 (27.6)
1970-1980	51 (9.7)	255 (9.7)
Age at certification, y		
<20	26 (4.9)	60 (2.3)
20-24	269 (50.9)	1588 (60.4)
25-29	103 (19.5)	426 (16.2)
30-39	105 (19.9)	452 (17.2)
≥40	25 (4.7)	102 (3.9)
Time between certification and index date, y†		
<5	23 (4.4)	115 (4.4)
5-9	36 (6.8)	180 (6.8)
10-14	82 (15.5)	410 (15.6)
15-19	85 (16.1)	425 (16.2)
20-29	198 (37.5)	984 (37.4)
30-39	82 (15.5)	409 (15.6)
≥40	22 (4.2)	105 (4.0)
Year of breast cancer diagnosis		
<1950	2 (0.4)	...‡
1950-1959	14 (2.7)	...
1960-1969	47 (8.9)	...
1970-1979	162 (30.7)	...
≥1980	303 (57.4)	...
Age at breast cancer diagnosis, y		
<35	66 (12.5)	...
35-44	151 (28.7)	...
45-54	170 (32.2)	...
≥55	141 (26.7)	...

*Percentages may not total because of rounding.

†The index date is the date of breast cancer diagnosis for cases and the equivalent date for controls. For a control, the time between certification and index date is equivalent to the time between certification and breast cancer diagnosis of her corresponding case.

‡Ellipses indicate not applicable.

From the self-reported medical histories, 628 breast cancers were identified among the 79 016 female respondents. Only one breast cancer occurred among the 25 534 male respondents. Women who responded to the abbreviated questionnaire were excluded from the present analysis because breast cancer risk factors and occupational histories were not available. This exclusion reduced the number of breast cancers by 67. Of the remaining 561 reported breast cancers, 15 were excluded because of erroneous dates for breast cancer diagnosis, 12 were excluded because the diagnosis occurred before the date of certification, four were histologically denied, one failed to match to any control, and one was reported by a family member. Overall, breast cancers in 528 women were available for analysis, of which 468 were histologically confirmed based on pathology reports. Histological reports were unavailable for 60 cases, mainly because the diagnoses occurred before 1980) and information was difficult to obtain.

An attempt was made to match five controls each breast cancer case based on sex, date of birth (±5 years), calendar year of certification (±2 years), and length of time between certification and an index date (year of breast cancer diagnosis) (Table 1). For a control, the time between certification and index date would be the same as the time between certification and breast cancer diagnosis of the matched case. Overall, 2628 controls were selected; 522 cases were matched to five controls; and two cases each were matched to four, three, and two controls, respectively.

Risk Factors

The 16-page questionnaire contained questions on established and suspected risk factors for breast cancer.[4] Details were obtained on age at menarche, reproductive history, age at menopause, family history of breast cancer, breast biopsy as an indicator of benign breast pathology, height, weight, alcohol consumption, cigarette smoking, use of birth control pills-and Postmenopausal estrogens, use of hair dye, and education as a measure of socioeconomic status.

Estimates of occupational exposure to radiation were made in several ways. Number of years worked as a technologist had been associated with cumulative radiation exposure[2] and could be calculated from responses to the questionnaire. Annual exposures received before 1950 were likely higher than those received in later years because radiation protection practices were not se strict before 1950. Thus, decade of certification would be related to amount of radiation received. For many registrants working in 1979 or later, cumulative occupational exposures were available by linking records with a large commercial dosimetry company. While 64% of all registered technologists had information available in these files, only 34% of the breast cancer cases and 35% of the controls had computerized exposure records. The reason for the lower proportion of dosimetry information was because breast cancer cases and matched controls were older and more likely to have stopped working before 1979, the first year computerised records were available, than other questionnaire respondents.

Personal exposure to medical x-rays was also determined. Chest fluoroscopies or multifilm x-ray procedures that could result in direct exposure to breast tissue would include upper gastrointestinal series and barium swallow, spinal x-rays, and certain angiographic procedures. Other x-ray examinations, such as dental procedures, barium enemas, and kidney-ureter-bladder films, would contribute only a negligible amount of radiation to the breast.[5]

Statistical Methods and Analysis

The measure of association between specific risk-factors and the develop ment of breast cancer was the relative risk (RR), approximated by the prevalence odds ratio (comparing the odds of exposure of breast cancer cases with that of controls) with 95% confidence intervals (CIs). Conditional logistic regression methods were used to compare

Table 2.—Relative Risk (RR) of Developing Breast Cancer Among Radiologic Technologists According to Established Breast Cancer Risk Factors

Variable	No. of Case Subjects (n=528)	No. of Controls (n=2628)	RR*	95% CI†
Age at menarche, y				
≥15	50	307	1.0	...
13-14	190	1085	1.06	0.75-1.50
11-12	228	1002	1.40	0.99-1.98
<11	37	118	1.79	1.09-2.94
Unknown/missing	23	116	1.57	0.87-2.83
Age at menopause, y				
<45	79	497	1.0	...
45-49	57	270	1.24	0.83-1.85
≥50	71	311	1.40	0.94-2.08
Not menopausal	293	1360	1.43	1.05-1.97
Unknown/missing	28	190	0.88	0.52-1.47
Age at first birth, y*‡				
<25	149	913	1.0	...
25-29	123	592	1.27	0.96-1.68
≥30	69	296	1.37	0.97-1.93
Nulliparous	179	788	1.36	1.04-1.78
Unknown/missing	8	39	1.38	0.60-3.08
No. of children*				
1	68	291	1.0	...
2-3	199	998	0.98	0.70-1.37
4-5	44	282	0.85	0.54-1.35
≥6	9	62	0.94	0.41-2.13
Unknown/missing	29	207	0.75	0.45-1.26
Family history of breast cancer				
None	338	1974	1.0	...
First-degree relative	88	247	2.07	1.56-2.74
Other relative	90	330	1.51	1.15-1.97
Unknown/missing	12	77	1.16	0.57-2.35
Breast biopsy				
Never	422	2225	1.0	...
Yes	97	328	1.53	1.17-2.00
Unknown/missing	9	75	0.83	0.29-1.39

*Matched RR also adjusting for other established breast cancer risk factors. Age at first birth rather than number of children was used in the model. Analyses with number of children were not conducted with age at first birth in the model and vice versa.

†CI indicates confidence interval; ellipses, referent category.

‡The RRs using younger than 20 years as the referent were 1.0, 1.8, 2.3, 2.5, 2.3, and 2.4 for younger than 20 years, 20 through 24 years, 25 through 29 years, 30 years or older, nulliparous, and unknown/missing, respectively, but the number of cases younger than 20 years (only nine) was especially small.

risk factor exposure in cases and individually matched controls.[6] Risk factors were often grouped into several categories, and RRs were computed with the nonexposed or low-exposed group as the referent category. Tests for trend were baaed on the likelihood ratio test.

Breast cancers could have occurred many years before the survey. Therefore, care was taken in classifyingwomen with respect to the timing of the characteristic of interest. Menopause, for example, could have occurred before or after the date of breast cancer diagnosis (or equivalent index date for the matched controls). If an event occurred after the index date, then the woman was considered not to have the characteristic of interest in the analysis. For example, women whose children were born after their index dates were considered to be nulliparous in these analyses. Similarly, some procedures, such as breast biopsy, were performed in association with diagnosis or early symptoms of breast cancer, and such events were not counted. Breast biopsies were entered into the analysis only if they occurred at least 1 year before the diagnosis of cancer for the case subjects or the equivalent index dates for the controls. Reason for biopsy was not asked. A first-degree relative was considered to be a mother, sister, or daughter.

Radiation dose information was carefully evaluated. Controls may have larger cumulative doses than cases simply because they continued to work and accumulate dose, where as the cases may have stopped working at the time their cancers were diagnosed. Again, appropriate consideration was taken to ensure that exposures after or at the time of diagnosis were excluded from consideration. some analyses were restricted only to the 303 breast cancers in women whose cancers were diagnosed in the 1980s and near the date of questionnaire response.

RESULTS

Radiologic technologists who developed breast cancer were similar to their matched controls in terms of year of birth (mean, 1930) and year of certification (mean, 1956). More than half of the women were certified before 25 years of age (Table 1). More than 55% of study subjects had been certfied for more than 20 years. The mean time between certification and questionnaire response was 29 years for both cases and controls, and both groups worked as radiologic technologists for an average of 15 years. The mean age at time of questionnaire response was 55 years for both cases and controls, ranging from 23 to 90 years. The mean age when breast cancer was diagnosed was 48 years, occurring an average of 22 years after certification. More than half(57%)of the breast cancers were diagnosed in the 1980s.

Breast Cancer Risk Factors

Analyses of established risk factors for breast cancer provided information on the likelihood of serious bias in this series (Table 2). AU such characteristics examined operated in the manner expected.[4] Increased risk of breast cancer was significantly associated with an early menarche, late menopause, nulliparity, late age at first birth, family history of breast cancer, and previous breast biopsy. Risk varied little with number of children after correcting for age at first birth. Any full-term pregnancy was linked to a 16% reduction in risk (RR=0.84; 95% CI, 0.67 to 1.05). The RR of breast cancer associated with a first birth after 30 years of age, compared with an age of younger than 20 years, was 2.5 (95% CI, 1.17 to 5.34).

Radiation Exposure

Overall, 63.8% of the cases and 62.6% of the controls had worked as radiologic technologists for 10 or more years (Table 3). Among women who worked more than 20 years, the RR for breast cancer was 1.13 (95% CI, 0.79 to 1.64). Various subgroup analyses were conducted to uncover any patterns of risk that might be related to occupational exposure (Table 3). Women certified before 1955 (220 cases) likely received the highest annual exposures but showed no evidence of increased risk with years worked, nor did women first certified before 25 years of age (295 cases) whose young age at first exposure might place them at higher risk. There was no evi-

Years worked as a radiologic technologist				
<5	80	331	1.0	...
5-9	126	605	1.03	0.73-1.47
10-19	182	941	0.95	0.67-1.35
≥20	155	703	1.13	0.79-1.64
Years worked, cancers diagnosed in 1980 or later				
<5	29	167	1.0	...
5-9	65	326	1.00	0.61-1.64
10-19	107	536	1.06	0.66-1.69
≥20	98	446	1.21	0.75-1.96
Years worked, women certified before 1955				
<5	23	129	1.0	...
5-9	46	238	0.95	0.54-1.67
10-19	64	302	0.99	0.57-1.70
≥20	85	399	1.03	0.60-1.76
Years worked, women certified in 1955 or later				
<5	37	202	1.0	...
5-9	80	367	1.12	0.72-1.75
10-19	118	639	0.94	0.61-1.47
≥20	70	304	1.21	0.74-2.00
Years worked, women certified at younger than 25 years				
<5	44	222	1.0	...
5-9	80	369	1.04	0.68-1.61
10-19	108	541	0.92	0.60-1.40
≥20	62	320	0.88	0.55-1.43
Years worked, women certified at 25 years of age or older				
<5	16	109	1.0	...
5-9	46	236	1.14	0.61-2.15
10-19	74	400	1.04	0.56-1.93
≥20	93	383	1.61	0.87-3.00
Years worked, cancers diagnosed at younger than 45 years				
<5	38	172	1.0	...
5-9	71	298	0.93	0.58-1.49
10-19	79	499	0.55	0.34-0.89
≥20	28	103	1.04	0.53-2.02
Years worked, cancers diagnosed at 45 years of age or older				
<5	22	159	1.0	...
5-9	55	307	1.21	0.70-2.09
10-19	103	442	1.62	0.97-2.70
≥20	127	600	1.46	0.88-2.42

[redacted]

†Years worked could not be computed for five cases and 48 controls.
‡Matched analysis also adjusting for establishing breast cancer risk factors (see Table 2).
§CI indicates confidence interval; ellipses, referent category.

dence of a radiation risk for the 217 women whose breast cancer developed before 45 years of age. For women whose breast cancer developed after 45 years of age, there was a suggested trend for increased risk over categories of years worked, but the trend was not significant ($P = .2$).

Dosimetry records were not available for 65% of study subjects because many of the women had either retired before 1979, the first year that computerized records were accessible, or a different dosimetry service had been used than the one available for this study. Attempts to reconstruct complete exposure histories by contacting former employers were unsuccessful because records no longer existed or the former employer was no longer in business, which was common for those who held jobs before 1960. Based on available dosimetry records, there was no evidence for an increasing risk over categories of dose (Table 4). Indicators of potential high occupational exposures, such as allowing other technologists to practice x-ray techniques on themselves or to frequently hold patients during radiologic examinations, also were not linked to breast cancer. Jobs that involved fluoroscopy, radiotherapy, radioisotopes, or ultrasound were not correlated with breast cancer risk.

A wide range of radiologic procedures performed on the technologists for personal illnesses were analyzed, but there was no evidence for any association with breast cancer. More than 70% of the female study subjects had received fluoroscopic or multifilm procedures, but again such examinations were not related to breast cancer risk.

Breast Cancers Diagnosed During the 1980s

This study includes women whose cancer occurred over many years and who survived to the time of the questionnaire mailing. If survival was associated with breast cancer risk factors and radiation exposure, then analyses including the surviving cases might result in spurious findings. Analyses restricted to the 303 breast cancers diagnosed during the 1980s, and close in time to the questionnaire response, provided little evidence for an increasing risk with years worked (*P* for trend=.19). For those women diagnosed in the 1980s and who were occupationally exposed to radiation for 20 or more years, the RR was 1.21 (95% CI, 0.75 to 1.96) (Table 3).

Other Risk Factors

The survey also contained questions on a variety of demographic, lifestyle, and suspected breast cancer risk factors (Table 5). Significant risks for breast cancer were associated with thyroid conditions, weekly consumption of more than 14 alcoholic drinks, and living in the northeastern United States. No clear patterns were seen for Quetelet's index (weight in kilograms divided by the square of height in meters), miscarriage, abortion, cigarette smoking, oral contraceptive use, postmenopausal estrogen use, or hair dye use. Oral contraceptive use was also not related to breast cancer among the 217 women who developed breast cancer at younger than 45 years.

Based on only six cases, a personal history of thyroid cancer was correlated with a significant increased risk of breast cancer (RR=5.36; 95% CI, 1.64 to 17.5). Hyperthyroidism was also a significant risk indicator (RR=l.66; 95% CI, 1.02 to 2.71). Current residence in one of 12 northeastern states (New York, Massachusetts, Vermont, New Hampshire, Connecticut, New Jersey, Maryland, Delaware, Rhode Island, Pennsylvania, Maine, or Washington, DC) was significantly linked to breast cancer (RR=l.66; 95% CI, 1.19 to 2.3), even after adjustment was made for all known breast cancer risk factors. State of birth was similarly associated with risk for breast cancer but not after adjustment. was made for state of residence. Urban

Yes	495	2446	0.99	0.57-1.70
Unknown/missing	15	91	0.92	0.43-1.99
Ever worked with radioisotopes				
No	364	1808	1.0	. . .
Yes	109	545	1.03	0.80-1.32
Unknown/missing	55	275	0.91	0.67-1.24
Ever worked with radiotherapy				
No	242	1182	1.0	. . .
Yes	248	1268	0.90	0.74-1.10
Unknown/missing	38	178	1.11	0.75-1.65
Ever worked with any ultrasound				
No	417	2043	1.0	. . .
Yes	67	353	0.93	0.70-1.25
Unknown/missing	44	232	0.99	0.70-1.41
[illegible]				
0	418	2050	1.0	. . .
1-9	64	332	0.93	0.69-1.25
≥10	30	154	0.93	0.61-1.41
Unknown/missing	16	92	0.82	0.46-1.44
No. of times held a patient during radiologic examination				
0	44	177	1.0	. . .
1-9	61	293	0.91	0.59-1.42
10-24	84	364	0.98	0.64-1.50
25-49	77	387	0.82	0.53-1.27
≥50	241	1306	0.73	0.50-1.07
Unknown/missing	21	101	1.00	0.55-1.83
Personal history of upper gastrointestinal examination				
No	271	1228	1.0	. . .
Yes	252	1383	0.62	0.21-1.78
Unknown/missing	5	17	0.79	0.27-2.27
Personal history of any fluoroscopic or multifilm procedure				
No	144	735	1.0	. . .
Yes	383	1889	1.00	0.80-1.25
Unknown/missing	1	4	1.17	0.12-11.4

*Matched analysis also adjusting for establishing breast cancer risk factors (Table 2).
†CI indicates confidence interval; ellipses, referent category.

residence, defined by ZIP code designations from the Census Bureau, was not related to breast cancer risk. Adjustment for these demographic and suspected breast cancer risk factors did not meaningfully change the risk estimates associated with radiation exposure.

Nonresponders

Among the 105 365 women who were certified members of the ARRT, 79 016 (79.6%) responded to our surveys (69 510 responded to the full questionnaire and 9506 responded to an abbreviated questionnaire). Of the total number of certified women, 2574 (2.4%) were never located, 3539 (3.4%) had died, and 20 256 (20.4%) failed to return the questionnaire. Among those who died, 425 breast cancers were recorded as the cause of death in comparison with 431 expected breast cancers based on mortality rates in the general population (RR=0.99; 95% CI, 0.9 to 1.1). Thus, women employed as radiologic technologist were not at increased risk of death from breast cancer compared with women in the general population born in the same calendar years.

Persons whom we were unable to locate tended to be more similar to those who died than to those known to be alive. Proportionately more were born before 1940, certified before 1950, and certified after 30 years of age. Conceivably, many unlocated technologists may have died before 1979 when national death registration began. A special effort, including telephone contact, was made to encourage nonrespondents to complete a short questiomaire. This effort resulted in an additional 9506 women respondents; information on breast cancer and a few other variables was also obtained. The proportions of women with breast cancer reported on the long and abbreviated questionnaire were similar (6.7 and 7.0 per 1000, respectively). Nonrespondents were similar to respondents with regard to most characteristics available for evaluation. Thus, it seems unlikely that differential reporting bias would have adversely affected the study findings.

COMMENT

Few studies of occupational groups exposed to radiation have included women, and the current investigation is by far the largest. In China, approximately 5400 female x-ray workers were followed up for an average of 16 years from 1950 to 1985, and a nonsignificant 1.5-fold risk of breast cancer was reported based on 20 incident cases.[7] Women employed as radium dial painters before 1950 who were exposed to excessive gamma radiation from radium paint containers were at elevated risk for breast cancer, but the increase has not been clearly linked to radiation exposure and might be attributable to reproductive factors such as nulliparity.[8,9] Pioneering x-ray workers, primarily men, in the United States and other countries. were found to be at increased risk for various cancers, but the absence of accurate dosimetric information has precluded risk quantification. For men working in the nuclear industry, estimates of radiation exposure can be made based on personal dosimeter readings, but the evidence for radiation-related risks remains somewhat equivocal.[10,11]

Ionizing radiation was first linked to increased breast cancer rates in women frequently exposed to x-ray fluoroscopies during lung collapse treatments for tuberculosis.[1,12,13] Excess risks were also found in atomic bomb survivors,[14,15] in women treated for benign and malignant breast disease,[16-18] and following radiotherapy for Hodgkin's disease and enlarged thymus glands.[19,20] Suggested risks have been reported following excessive spinal x-ray exposure during adolescence for scoliosis[21] and following treatments for childhood cancer[22] and hemangioma.[23] No enhanced risk of breast cancer has been seen following exposures for ankylosing spondylitis,[24] for cardiac catheterization,[25] for cervical cancer,[26] or with radioactive iodine administrations.[27] Reasons for the lack of an effect in several series may be attributable to the associated low radiation doses to breast tissue or to the relatively elderly age of some of the populations studied. Studies of radiogenic breast cancer indicate that linearity best describes the relationship between dose and risk, that age at exposure is an important determinant of risk with exposures after the menopausal years carrying minimal risk, and that latency is inversely related to age at exposure, ie, that radiation-induced breast cancers develop late in life when the spontaneous Occurrence is also high.[28]

Absence of Association and Study Limitations

Possible reasons for the absence of a clear association between employment and breast cancer in our occupational series include low cumulative doses, imprecise measures of dose, relatively short follow-up at older ages, a lower risk than expected due to the nature of the exposure, and response bias.

First, the actual exposure might have been very low. While the expected RR from 1 Gy is on the order of 1.7 following exposures at 20 years of age, the risk decreases to 1.07 if the dose is 0.1 Gy.[1] Relative risks of this magnitude are impossible to detect epidemiologically, and thus, positive results would only be possible if there were a range of exposures with some meaningful proportion of women receiving about 1 Gy. Biological dosimetry studies are ongoing to more accurately estimate cumulative exposures for long-term radiologic workers. The glycophorin-A mutational assay for red blood cells and fluorescent in situ hybridization techniques for translocation analysis of blood lymphocyte chromosomes are being applied as biological dosimeters to assess prior radiation exposures.[29,30] Preliminary results indicate that some technologists received career doses in excess of 1 Gy. Unfortunately, in the absence of dosimetry information for most women employed during the first half of this century, it is difficult at this time to assess accurately the actual power of the current study to detect a significant risk of breast cancer. Among the long-term workers who likely received the highest exposure, sampling variability was such that RRs greater than 1.64 could be ruled out with high assurance.

Second, years worked is only a crude indicator of actual radiation dose, and misclassification in exposure could obscure underlying trends. In addition, it was not possible to distinguish full-time from part-time employment.

Table 5.—Relative Risk (RR) of Developing Breast Cancer Among Radiologic Technologists According to Selected Demographic, Lifestyle, and Suspected Breast Cancer Risk Factors

Variable	No. of Case Subjects (n=528)	No. of Controls (n=2628)	RR*	95% CI†
Education				
Radiologic technical school	330	1678	1.0	...‡
Some college	170	849	0.99	0.80-1.22
Some graduate school	28	101	1.43	0.90-2.26
No. of alcoholic drinks per week				
None	133	622	1.0	...
<1	183	986	0.86	0.67-1.10
1-6	135	665	0.91	0.69-1.20
7-13	57	310	0.86	0.61-1.22
≥14	13	28	2.12	1.06-4.27
Unknown/missing	7	17	1.91	0.74-4.92
Cigarettes smoked, packs per day				
Never smoked	237	1089	1.0	...
Ex-smoker	185	828	1.01	0.81-1.25
Current ≤1	57	434	0.60	0.44-0.83
Current >1	45	261	0.81	0.57-1.14
Unknown/missing	4	16	1.45	0.47-4.49
Weight, kg				
<56	113	610	1.0	...
56-65	165	896	1.01	0.77-1.31
66-74	126	560	1.22	0.91-1.62
≥75	106	474	1.20	0.89-1.62
Unknown/missing	18	86	1.15	0.65-2.03
Height, cm				
<155	58	291	1.0	...
155-160	198	1063	1.02	0.74-1.42
161-165	141	707	1.07	0.75-1.51
≥166	125	517	1.34	0.93-1.92
Unknown/missing	6	50	0.68	0.27-1.69
Quetelet's index				
<22	176	942	1.0	...
22-24	158	792	1.05	0.83-1.34
25-27	88	366	1.23	0.91-1.65
>28	85	419	1.07	0.79-1.43
Unknown/missing	21	109	1.03	0.62-1.71
Miscarriage				
Never	405	1997	1.0	...
Yes	122	617	0.99	0.79-1.25
Unknown/missing	1	12	0.37	0.04-3.38
Oral contraceptive use, y				
None	317	1529	1.0	...
<2	44	197	1.02	0.70-1.48
2-4	68	310	1.05	0.75-1.46
5-9	51	293	0.85	0.59-1.22
≥10	26	162	0.64	0.40-1.02
Unknown/missing	22	117	1.01	0.61-1.68

(continued)

Third, it is apparent that radiogenic breast cancers have along induction period. Conceivably, the follow-up may still be too short to discern radiation effects among women at older ages. However, the mean age of cases and controls was 55 years, indicating that there were substantial numbers of women employed before 1960 who were followed up for more than 30 years and who have entered the ages of later life when cancer rates become high.

Fourth, although fractionated exposures do not appear to produce fewer breast cancers than acute exposures of the same total dose,[1] conceivably, the very low dose fractions experienced during normal employment as a technologist might allow the body to repair radiation damage more efficiently than it could for higher dose fractions.[13]

Fifth, there could be differential response bias among women with breast cancer who were employed for the longest periods and who maybe less likely to respond to the questionnaire. This bias seems unlikely since a telephone contact of more than 9600 nonrespon-

Table 5.—Relative Risk (RR) of Developing Breast Cancer Among Radiologic Technologists According to Selected Demographic, Lifestyle, and Suspected Breast Cancer Risk Factors (cont)

Variable	No. of Case Subjects (n=528)	No. of Controls (n=2628)	RR*	95% CI†
Postmenopausal estrogen use, y				
None	403	1937	1.0	. . .
<2	6	63	0.53	0.23-1.26
2-4	29	164	0.88	0.56-1.38
5-9	19	101	0.86	0.51-1.45
>10	24	122	1.03	0.63-1.69
Unknown/missing	47	241	1.08	0.76-1.54
Hair dye use				
Never	368	1867	1.0	. . .
Yes	155	734	1.08	0.87-1.33
Unknown/missing	5	27	1.00	0.37-2.66
Any thyroid condition				
No	426	2142	1.0	. . .
Yes	92	426	1.06	0.82-1.36
Unknown/missing	10	60	0.91	0.45-1.83
Hyperthyroidism				
No	490	2464	1.0	. . .
Yes	23	70	1.66	1.02-2.71
Unknown/missing	15	94	0.86	0.49-1.52
Hypothyroidism				
No	477	2309	1.0	. . .
Yes	36	225	0.75	0.52-1.09
Unknown/missing	15	94	0.82	0.47-1.45
Thyroid cancer				
No	507	2528	1.0	. . .
Yes	6	6	5.36	1.64-17.5
Unknown/missing	15	94	0.85	0.48-1.49
Goiter				
No	497	2478	1.0	. . .
Yes	16	56	1.25	0.72-2.24
Unknown/missing	15	94	0.85	0.48-1.49
Region of birth				
Other than Northeast	396	2082	1.0	. . .
Northeast‡	79	305	1.07	0.75-1.51
Unknown/missing	53	241	1.03	0.69-1.54
Region of last known residence				
Other than Northwest	434	2330	1.0	. . .
Northeast‡	94	298	1.66	1.19-2.30
Current residential area				
Rural	95	527	1.0	. . .
Urban	410	2086	1.05	0.82-1.35
Unknown/missing	23	15	8.55	4.17-17.5

*Matched analysis also adjusting for common breast cancer risk factors (Table 2).
†CI indicates confidence interval; ellipses, referent category.
‡Connecticut, Delaware, Massachusetts, Maryland, Maine, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and Washington, DC.

dents revealed no unusual pattern in breast cancer reporting or demographic characteristics. Further, a mortality analysis revealed that 425 women had died from breast cancer, which might be expected in a general population of similar ages and dates of birth. Finally, it was reassuring that all established breast cancer risk factors operated as expected in this study of self-reported prevalent cases of breast cancer.

Other Breast Cancer Risk Factors

Demographic, life style, and suspected breast cancer risk factors were not found to confound or distort the association between breast cancer and various measures of radiation exposure. Consistent with previous reports,[31] breast cancer risk for technologists residing in the northeast United States tended to be higher than for those residing in other regions. The reasons for the geographic variation within the United States are not entirely clear and are the subject of intense current research.

Oral contraceptive use was not linked to breast cancer, similar to some stud-

tails to evaluate whether certain exposures, such as near the time of menarche, might be harmful.[33] Postmenopausal estrogen use was also unrelated to breast cancer risk in our study, but again we were unable to test whether a modest increase in risk might be present for long-term users or among certain subgroups.[34,35]

We found little evidence to support a causal link between breast cancer and use of hair dyes[36] or cigarette smoking.[37]

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